A Long Pulse CuBr Vapor Oscillator for Laser Monitor Applications

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Abstract. The paper discusses the perspectives of application of a long pulse CuBr vapor oscillator for laser monitors. The influence of excitation conditions of the copper bromide vapor laser on the lasing pulse duration is discussed. It is revealed that increased pulse duration of lasing up to 200 ns and more is observed in unstable mode of the discharge. Laser monitors based on the long lasing pulse CuBr vapor oscillators can be demanded for distant objects monitoring.

1. Introduction

A number of non-destructive testing tasks need visualization of processes shielded by intensive background lighting. Such processes occur in interaction areas of a matter and powerful flow of energy (laser material processing, film deposition in a discharge, irradiation of biological tissues by a concentrated flow of energy, surface modification by exposure of electron beams), self-propagating high-temperature syntheses, discharge plasmas etc.

One of the powerful tools for observing objects and processes shielded by intensive background lighting is a laser monitor based on high-frequency monoatomic copper or copper bromide vapor lasers [1–7]. The temperature of objects under observation by means of such laser monitor can reach up to 40000 K and more [7]. The copper vapor lasers and brightness amplifiers based on them radiate at two different wavelengths in the visible range of the spectrum, namely 510.6 nm (green) and 578.2 nm (yellow).

The operating principle of a laser monitor is similar to the operating principle of a laser projection microscope [8] and is as follows. The object under observation is illuminated by an amplified spontaneous emission of a brightness amplifier. After that the reflected from the object radiation is amplified and projected onto a screen or the sensor of a digital CCD-camera. This type of a laser monitor scheme is widely used and called monostatic [3].

There are several embodiments of the monostatic laser monitor scheme that are shown in figure 1, *a* – short-focus lens is located close to the brightness amplifier (typical scheme), *b* – short-focus lens is located at a distance of several meters from the brightness amplifier, and *c* – long focal-length lens is located close to the brightness amplifier.

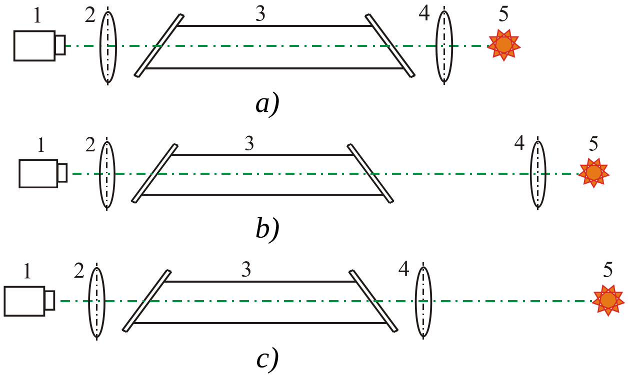


Figure 1. Laser monitor schemes: 1 – CCD-camera; 2, 4 – optical lenses; 3 – a brightness amplifier; 5 – an object under observation.

Visualizing distant objects (situated in a distance of a few meters or tens of meters) by means of a laser monitor is of special interest [9, 10]. The figure 1b and *c* shows the modifications of the typical scheme of a laser monitor for visualizing distant objects depending on the relative position of a brightness amplifier, optical lens, and an object under observation. The scheme in figure 1b has obvious limitations caused by the need of placing the lens in close proximity to the object under observation. Such a scheme is not acceptable for visualizing processes passing at high temperature or accompanied by the combustion product splashing. Moreover, when the lens is moved away from the brightness amplifier the area of view is reduced [11]. Thus, the most suitable variant of a laser monitor monostatic scheme (based on a single brightness amplifier) for observing distant objects is the one illustrated in figure 1c.

In a case of visualizing distant objects by means of a laser monitor the pulse duration of lasing can be of fundamental importance. Thus, in a case of monostatic scheme of laser monitor that is more economical in comparison with a bistatic scheme (a scheme with two brightness amplifiers [3]) the duration of existence of laser level population inversion limits the longest possible distance to an object under observation. The lasing pulse duration of copper vapor laser (copper bromide vapor laser) is influenced by such factors as peculiarities of active medium, composition and component ratio of working mixture, geometry of a gas-discharge tube (GDT), excitation conditions, in particular the discharge pumping pulse waveform. Typical lasing pulse duration of copper vapor laser is 20–40 ns [12–15]. In a case of CuBr laser the typical pulse duration of lasing can reach 80 ns [16].

The maximum possible pulse duration of lasing on self-terminating transitions is estimated accurate enough in [17]. According to the work estimations the maximum possible pulse duration of copper vapor laser in the self-terminating mode is limited to 175 and 206 ns for the transitions of 510.6 and 578.2 nm, respectively. Increasing the pulse duration of lasing more than estimated values is possible by means of controlled current restriction of the discharge by a series connection of an additional tacitron in the discharge circuit [18–20]. The record radiation pulse duration was achieved to be 230 ns for copper vapor laser [19] and 320 ns for CuBr laser.

Using systems of controlled current restriction of the discharge is not acceptable in low-cost applications. The aim of the current research is to investigate an influence of excitation conditions of CuBr laser on the pulse duration without using an additional system of controlled current restriction of the discharge. It should be noted that this research is not aimed at increasing the energy parameters of the laser but only at the possibility of lasing with radiation pulse duration of the order of 200 ns. In laser monitor applications the duration of amplification is more crucial than the power of radiation. Therefore, it is quite acceptable compromise to increase the duration of existence of population inversion to the detriment of power and energy of radiation.

2. Experimental technique

In the present research it was employed CuBr lasers with external heating the active region of the GDT which was also used in [21, 22]. The active part of GDT (90 cm in length and 5 cm in diameter) was inserted into an external heater to provide the capability of stabilizing heating temperature of the GDT. The heating temperature of the GDT was measured and controlled by a thermocouple and a microcontroller. Pressure of buffer gas (neon) in the GDT was 30 Torr.

Pumping active medium of GDT was carried out by means of a scheme of pulsed charge of a storage capacitor and its direct discharge by a thyratron TGI1-1000/25 [22]. In the experiments the PRF of discharge excitation was set by means of digital generator GW Instec SFG-72120 and varied in the range of 1–10 kHz.

As sensors of voltage on the GDT electrodes, current through the GDT, and laser pulse, were used P6015A Tektronix voltage probe, 8450 Pearson Current Monitor, and FC-22 coaxial photoelectric cell, respectively. The signals from the corresponding sensors were routed to inputs of WJ-324 LeCroy digital oscilloscope. Pulse duration of lasing was taken at the pulse base (at the level of 5% of the pulse amplitude).

3. Results and discussion

One of the most influencing parameters of operation is PRF of excitation. Figure 2 shows a result of influence of the PRF of discharge excitation on the pulse duration of lasing.

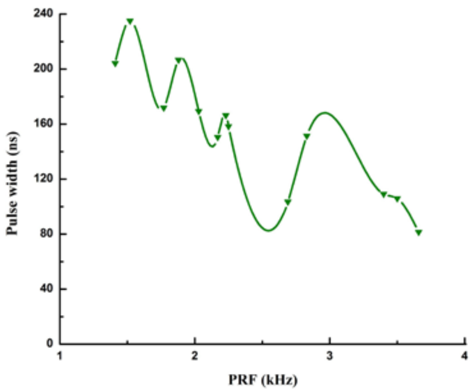


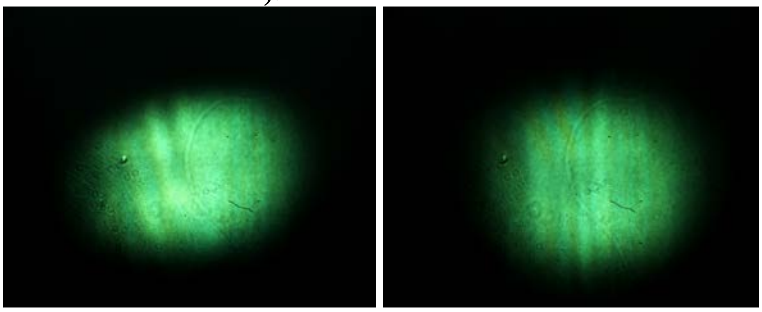
Figure 2. Influence of the PRF of excitation on the pulse duration of lasing. The heating temperature of the reservoir with CuBr powder is 390°C, voltage on the rectifier is 195 V, capacitance of storage capacitor is 4.95 nF.

As one can see (figure 2) at decreasing the excitation PRF the pulse duration of lasing is increased. Pulse duration of the CuBr laser achieved up to 200 ns and even more (figure 2). However, at the same time decreasing the excitation PRF resulted in a deterioration of the discharge shape. In this case the discharge contracts and moves (it is observed how the discharge current changes the area of flowing) inside the GDT. It should be mentioned that according to the work [23] the longer pulse duration of lasing was observed at higher value of the storage capacitor. Considerable reducing excitation PRF leads to disruption of the discharge. Higher storage capacitor value allowed working at lower PRF of discharge excitation and as a result to observe broader pulse of lasing.

According to our assumptions increasing the pulse duration of lasing supposedly may be caused by a spatial-temporal inhomogeneity of the discharge, namely by shifting the discharge within the cross section of the GDT to the colder areas where the conditions for realizing population inversion is more favorable. Thus, the population inversion occurs in different parts of the GDT active volume and in the different instant of time. But at the same time moving the discharge inside the GDT causes deterioration of laser beam quality.

In the work it was also carried out an estimation of laser beam profile quality by a simplified technique similar to [24]. Figure 3 shows photographs of laser beam profiles recorded by FastCam

HiSpec1 CCD camera. The exposition of CCD camera was 2 μs. Thus CCD camera recorded images formed by single pulses of lasing. The shown photographs correspond to different pulse durations of lasing. In the case when the pulse duration of lasing was 170 ns (figure 3*a*) the CuBr laser oscillation was characterized by a deformation of laser beam profile. Figure 3 allows comparing deformations of laser beam profile at excitation conditions corresponding different pulse duration of lasing. To use the active element of a laser as a brightness amplifier in a laser monitor the laser beam profile should be characterized as uniform as possible distribution. The longest obtained pulse of lasing with at the same time satisfactory radial distribution of laser beam profile was 100 ns. Laser pulse duration of 100 ns is sufficient for visualizing objects situated in a distance of 15 m from the brightness amplifier by a laser monitor (a case of the monostatic scheme).



a *b*

Figure 3. The photographs of laser beam profiles corresponding to: *a*) CuBr laser pulse duration of 170 ns, PRF of excitation of 2 kHz; *b*) CuBr laser pulse duration of 100 ns, PRF of excitation of 2.6 kHz. The heating temperature of the reservoir with CuBr powder is 390°C, voltage on the rectifier is 195 V, capacitance of storage capacitor is 4.95 nF.

Figure 4 demonstrates dependence the pulse duration of lasing on the PRF of excitation at various heating temperatures of the reservoir with CuBr powder, i.e. at different copper bromide vapor content. The shown dependences just seemingly demonstrate the fact that increasing the pulse duration of lasing occurs in the case when the discharge transitions to the unstable mode. As one can see (figure 4) at increasing the concentration of copper bromide vapor the fluctuation of the pulse duration observes at higher values of the PRF. This fact correlates well with the corresponding shift of the critical frequency value at which the discharge transitions to the unstable mode.

In metal halide vapor lasers a pumping pulse provides not only the excitation of working atoms but also dissociation of metal halide molecules and heating the active medium. Therefore, this type of lasers is characterized by the presence of a lower lasing-action threshold of PRF which depends on the discharge excitation conditions. As one can see (figures 2 and 4) the lower lasing-action threshold for the current conditions is correspond to PRF of 1.5-2 kHz (see also [20]). The longest pulse durations of lasing are observed just at the low PRF (figures 2 and 4).

The waveforms analysis also showed that the lasing occurs with considerable delay after the thyratron triggering up to 200 ns (see also [23]). This delay is caused by the fact that decreasing PRF of excitation and energy deposited to the discharge lead to increasing pre-pulse resistance of the discharge and as a result the breakdown of the discharge becomes more difficult.

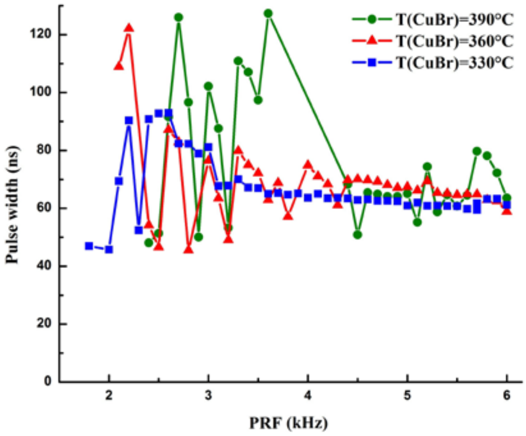


Figure 4. Influence of the PRF of excitation at various heating temperature of the reservoir with CuBr powder on the pulse duration of lasing. Voltage on the rectifier is 200 V, capacitance of storage capacitor is 1.65 nF.

4. Conclusions

Results of study the influence of excitation conditions of the copper bromide vapor laser on the pulse duration of lasing are presented. Increased pulse duration of lasing is revealed can be observed when the discharge transitions to an unstable mode. Such modes are achieved at low pulse repetition frequencies.

It is demonstrated that CuBr laser oscillation with pulse duration of lasing up to 235 ns at the laser pulse base can be obtained without using an additional system of controlled current limiting of the discharge. But at the same time the laser beam quality deteriorates appreciably as well. To use the active element of a laser as a brightness amplifier in a laser monitor the laser beam profile should be characterized as uniform as possible distribution. According to the results the longest obtained pulse of lasing with at the same time satisfactory distribution of laser beam profile was 100 ns. Laser pulse duration of 100 ns is sufficient for visualizing objects situated in a distance of 15 m from a brightness amplifier by a laser monitor (a case of the monostatic scheme).

Acknowledgments

The authors gratefully acknowledge Prof. G.S. Evtushenko of Tomsk Polytechnic University (Russia) for his interest to this work and helpful discussions.

The author, Miron Klenovskii, is expressing his gratitude to the Tomsk Polytechnic University for the opportunity to conduct scientific research in the TPU postdoctoral program.

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